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ABSTRACT

Do Good Carefully: The Long-Term Effects of DDT Exposure in Early Childhood on Education and Employment*

For decades, the debate on using DDT to control malaria has focused on the balance between immediate public health gains and ecological costs, ignoring DDT's long-term harmful effects on humans. Using data from the large-scale indoor residual spraying of DDT that took place in Taiwan in the 1950s, we estimate the long-term effects of DDT exposure in early childhood on education and employment in adulthood. Our identification hinges on the unexpected extension of DDT spraying even after malaria had already been largely brought under control. Our finding shows that DDT exposure in early childhood is associated with less education and worse employment in adulthood. However, the dose-response curves are non-linear.

JEL Classification: I1, Q5

Keywords: DDT, endocrine-disrupting chemicals, malaria, human capital, Taiwan

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1. Introduction

Malaria is one of the deadly infectious diseases that still plague many developing countries. Economists have studied its long-term adverse effects on humankind and have documented the substantial benefits of controlling it (Bleakley 2010; Cutler et al. 2010; Chang et al. 2014; Lucas 2010; Pathania 2014; Rawlings 2016; Shi and Lin 2018; Mora-Garcia 2018). On the other hand, the costs of malaria control methods are less understood. One effective method of malaria control is the use of DDT (dichlorodiphenyltrichloroethane), which has been widely used to kill *Anopheles* mosquitoes that transmit malaria parasites. Despite restrictions, DDT is still recommended by the World Health Organization (WHO), because it is not only effective but also affordable to many developing countries.[1]

In the 1970s, most countries started to ban large-scale use of DDT. However, it continued to be used for vector control in low doses in the form of indoor residual spray. At the time, very little was known about the harm that these low doses could inflict on human beings in the long run. Back then, due to lack of long-term data, the debate focused mostly on the balance between immediate public health gains and ecological costs (O'Shaughnessy 2008). However, at the turn of the twenty-first century, alarming new evidence emerged, and international organizations had to reappraise the latent human health effects of DDT (Turusov, Rakitsky and Tomatis 2002; Rogan and Chen 2005; Chang et al. 2018).

Some researchers started to consider the potential harms of DDT and other chemicals in terms of the endocrine-disrupting mechanism, which is the hypothesis that exposure to certain endocrine-disrupting chemicals (EDCs), including DDT, can disturb the human

[1] Under the Stockholm Convention on Persistent Organic Pollutants, DDT is mostly banned, except for use in disease vector control. More information is available at http://www.pops.int/. WHO issued its position statement in 2007 and revised it in 2011. The statement is available at http://apps.who.int/iris/bitstream/handle/10665/69945/WHO_HTM_GMP_2011_eng.pdf;jsessionid=9E42F21ED367100673502027A3DD4F08?sequence=1.

endocrine system (International Programme on Chemical Safety (IPCS) 2002; Diamanti-Kandarakis et al. 2009; Inter-Organization Programme for the Sound Management of Chemicals (IOMC) 2012; Gore et al. 2015). One key finding in this line of research is that at early developmental stages, correct levels of human hormones are essential for the development of human organs and systems. Too much or too little of a hormone can cause various irreversible disorders and impairments, some of which may not become evident until much later in life. Exposure to EDCs that mimic or antagonize our hormonal systems can change the development trajectory. Another key finding is that EDCs have complex dose-response curves and can be harmful even in extremely low doses, which were once considered harmless to humans. In particular, low doses of DDT used to be thought harmless, but this may not be the case.

Out of all the human organs, the brain is the most exquisitely sensitive to a wide range of hormones, making it highly vulnerable to EDC exposure (Gore et al. 2015). Although the brain starts to develop *in utero*, it continues to grow during childhood. The brain size increases four-fold during the preschool period, reaching roughly 90% of the adult brain size by age 6 (Stiles and Jernigan 2010). Hence, exposure to EDCs in early childhood could be more serious than exposure at later stages. In fact, numerous epidemiological studies have found that early-life markers of exposure to DDT and its metabolite DDE are associated with subsequent adverse cognitive and neurobehavioral outcomes, e.g., problems with IQ, processing speed, and language (Ribas-Fitó et al. 2006; Eskenazi et al. 2006; Gaspar et al. 2015; Kao et al. 2019; Fink et al. 2021).[2]

Alongside epidemiological studies, recent economics literature has also emphasized the role of early childhood environmental influences on the formation of cognitive ability,

[2] A recent study on dioxin, contained in Agent Orange, which had been used during the Vietnam War, found that exposure is associated with high blood pressure and loss of mobility (Le et al. 2021).

which in turn determines important socioeconomic outcomes later in life, such as schooling, employment, etc. (Cunha and Heckman 2007; Currie 2009, 2011; Almond and Currie 2011). It can be reasonably suspected that exposure to DDT in early life may have a long-term impact on the accumulation of human capital and employment in adulthood. This paper aims to estimate the effect on education and employment of DDT exposure in early childhood by analyzing the practice of large-scale indoor residual spraying of DDT in Taiwan in the 1950s.

Malaria had been extremely common in Taiwan in the early 1950s because of its subtropical climate. In 1952, Taiwan was estimated to have 1.2 million malaria cases among its 8 million residents (Department of Health (DOH) 2005). In response, the Nationalist government, which had just retreated from China to Taiwan, immediately initiated (with the help of the U.S.) an anti-malaria campaign, using indoor residual spraying of DDT as the major vector control.[3] The residual sprays were first used in the most malarious townships; then their use was gradually extended to the entire island. Within each township, DDT was sprayed on the surfaces inside every single house. The campaign quickly proved to be very successful. Malaria cases were slashed by two-thirds within one year, and by more than 90% the following year. The campaign was originally intended to conclude in 1955. However, the government unexpectedly decided to extend the island-wide DDT spraying for two more years in order to completely eradicate malaria, a goal eventually achieved in the early 1960s.[4]

This campaign had two important features that allow us to identify the effects of DDT exposure. First, the campaign directly exposed the children born during this period to technical-grade DDT at the critical developmental stage. Yet, the extent to which they were exposed to DDT varied substantially, depending on their year and place of birth. Second, the

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[3] An earlier anti-malaria campaign had taken place in Taiwan during the Japanese colonial period (1895-1945) (Chang et al. 2014). However, DDT had not been available at the time.
[4] The extension proposal was made to the Foreign Operation Administration of the U.S. and the Council for U.S. Aid, both of which later agreed to provide additional financial support to extend the campaign (DOH 2005).

rapid decline in malaria rates and the unexpected extension of the campaign greatly reduce the correlation between the DDT exposure and malaria exposure for these birth cohorts.[5] Therefore, we can use the variation in DDT exposure across birth cohorts and townships to identify the long-term effects of DDT exposure. We focus particularly on the cohorts born after malaria had largely been brought under control, while DDT residual spraying continued.

We compiled data from various *Taiwan Province Gazettes*, which record the DDT spraying in each township over this period. This allowed us to calculate the number of DDT spraying rounds that children born in the 1950s in each township were exposed to at age 0–5. We then linked the DDT exposure in early childhood to the number of years of schooling reported in the 2000 census and to employment status recorded in the National Health Insurance administrative data. Due to the lack of data on people's township of birth, the linkage is based on individuals' current township of residence. One concern of using current residence for matching is that people may have moved to another township. To mitigate the potential bias caused by migration, we considered only those people who still lived in their birth county, which is an administration level above township and was recorded in our data. We are not able to rule out the possibility of migration within county. However, we suspect that within-county migration is likely to attenuate our estimates. In the regressions, we further controlled for township and birth cohort fixed effects.

Our results show that on average, exposure to one DDT spraying is associated with a loss of 0.04 years of schooling. In terms of employment, we found that exposure to every additional DDT spraying lowers the probability of having an above-minimum-wage job by 0.25 percentage points. For both outcomes, we found no significant differences between men and women. In addition, we found a non-linear dose-response curve in both outcomes,

[5] It is more difficult to separate the effect of DDT exposure from the effect of malaria exposure for adults in this period, because adults had been exposed to malaria long before the campaign started.

although by and large, more exposure to DDT spraying is associated with greater losses in schooling years. One important caveat is that due to possible migration and mortality selection biases, our estimates are likely attenuated.

Our findings on socioeconomic outcomes, together with previous findings on health outcomes, imply that the cost of using DDT for vector control may have been underestimated. Since DDT is still used for vector control in many developing countries, more research is needed in order to comprehensively assess the full cost of using DDT to fight malaria and other infectious diseases.

The rest of the paper is organized as follows. Section 2 describes in detail Taiwan's anti-malaria campaign of the 1950s. Section 3 describes our empirical strategy. Section 4 lays out the details about the data used in this study. The empirical results are reported and discussed in Section 5. We conclude the paper in Section 6.

2. The Anti-Malaria Campaign in Taiwan in the 1950s

In 1951, the Taiwanese government drafted a four-year plan to contain malaria. Based on epidemiological data available at the time, the government divided the island into four areas, from the most malarious to the least: the hyperendemic, mesoendemic, hypoendemic, and non-malarious areas. At the core of the campaign was the use of DDT residual spraying to kill the *Anopheles* mosquitoes that transmit malaria parasites (DOH 2005).

A pilot program was conducted in 1952 in the Chishan District of Kaohsiung County in southern Taiwan to establish the standard procedures and field techniques to be used at the full scale. In particular, it was decided that DDT was to be sprayed once a year on the indoor surfaces—including ceiling, walls, and furniture—of every single house in each of the endemic areas. The dosage was 2 grams per square meter of technical-grade DDT. Residents were told not to wipe the residues off the surfaces.

After the pilot program, the main campaign began, first in the hyperendemic area in 1953, expanding to include the mesoendemic and hypoendemic areas in 1954. The spraying was scheduled to end in 1955. However, in 1954, the campaign plan was unexpectedly revised to extend the DDT spraying for two more years—1956 and 1957—in an attempt to completely eradicate malaria. In 1956, spraying was carried out in all of Taiwan except for a few non-malarious cities. In 1957, spraying was done only in the original hyperendemic area.

Because the DDT spraying started at different times in different areas, the total number of sprayings over 1952–1957, including the pilot program, also varied. The spraying schedule was based on the malaria distribution before 1952, and malaria declined rapidly soon after the campaign started. Malaria cases were slashed by two-thirds within one year, and by more than 90% the following year (DOH 2005). In addition, the government conducted annual malaria parasite surveys among preschoolers, i.e., children aged 2–7, by taking their blood smears; they found that the parasite rate dropped from 9.74% in 1952 to 4.58% in 1953, then to 1.18% in 1954, and to close to nil afterward (DOH 2005). Note that our study cohorts were preschoolers at the time of the campaign.

While malaria rates decreased, DDT spraying kept increasing over this period. In 1952, DDT was sprayed in only 21,682 buildings across 10 townships. The numbers soared to 184,653 buildings in 87 townships in 1953; 659,606 buildings in 262 townships in 1954; 630,633 buildings in 267 townships in 1955. They peaked at 730,468 buildings in 314 townships in 1956; then dropped slightly in 1957, the last year of the spraying campaign (DOH 2005). Eventually, in the early 1960s, malaria was completely eradicated in Taiwan. The WHO officially declared Taiwan malaria-free in 1965.

3. Empirical Strategy

Exposure to DDT in early childhood would have been particularly devastating for the following reasons. First, inside each sprayed house, infants and children were at a higher risk of exposure than adults. While adults were more aware of the chemical and could try to avoid it, infants and children were often exposed unknowingly and passively. Even in the uterus, the fetus can be exposed to DDT if the mother has direct contact with it. Breast-feeding is another pathway of exposure for infants in the neonatal period. Furthermore, when children became older and more mobile, their hand-to-mouth activities made them particularly likely to ingest the DDT residues. Second, the children would have been exposed at the critical stage when most of their organs and systems were still being developed. Any slight disturbance in the hormonal system can alter the development trajectory and lead to irreversible disorders or diseases, some of which may have a long latency period. Therefore, we focus here on exposure at age 0–5.

The number of DDT sprayings varied greatly across townships and years. Figure 1 shows the total number of DDT sprayings in 1952–1957 in each township, with darker areas indicating more sprays. The white area in the middle is the Central Mountain Ridge, which has very few inhabitants and thus was not sprayed at all. One of the challenges that we faced was the correlation between the malaria distribution and the DDT distribution. Since both malaria and DDT are expected to have negative impacts, the correlation between the two distributions could lead to overestimation of the DDT effect.

Fortunately, due to the fast decline of malaria and the unexpected extension of DDT spraying, the geographic distribution of DDT spraying quickly lost its correlation with malaria. Figure 2 shows the number of cases of malaria and the share of townships where DDT was sprayed. Before 1953, the number of malaria cases was quite high, but it dropped dramatically from 1953 onward. By contrast, the share of townships where DDT was sprayed increased after 1953, even though malaria cases had declined to a very low level. This allows us to isolate the DDT effect while mitigating the possible confounding due to malaria by limiting our study cohort to those born between 1953 and 1959. Later, in the results section, we confirm our conjecture of overestimation due to the correlation between malaria and DDT by additionally including the 1951 and 1952 cohorts, who were born when the two distributions were highly correlated.

Our data are population-wide and contain rich information on the education and employment of our study cohorts over about half a century after the residual spraying ended. This allows us to examine the long-term effects of DDT exposure in early childhood. In addition, our data include critical information about each individual's county and township of residence in December 2000 (when the 2000 Census of Population and Housing was done) and county of birth. These pieces of information together allow us to link our sample individuals' outcomes in adulthood to their DDT exposure in early childhood while controlling for cross-county migration. Our DDT exposure data are at the township level, which is an administrative division below county. To best utilize the available information, we first linked the childhood exposure data based on the township of current residence, then restricted the sample to those whose county of residence in 2000 matched their birth county. In other words, we limited our sample to those who still lived in their birth county in December 2000. By doing so, we were able to mitigate the potential bias from migration across county boundaries.

Despite our efforts, we still cannot rule out possible migration within counties. However, our restriction is likely to have mitigated most of the bias arising from migration. Using the 1980 and 1990 population census data, we found that over the 5-year window preceding each census, i.e., 1975–1980 and 1985–1990, more than 80% of people stayed in the same township (Panel A in Table A1). Out of the cohort of 1951–1959, more than 72% stayed in the same township over these 5-year windows (Panel B in Table A1). Of course, the census data do not cover the entire period between the time of exposure in the 1950s and the observation time of outcomes in 2000, and the data are thus are only suggestive. However, even if within-county migration took place, we argue that it would have most likely attenuated our estimates, for the following reason. In the 1950s, DDT was more heavily sprayed in rural than in urban areas. Between 1950 and 2000, the migration pattern within counties was mainly from rural to urban areas as a result of Taiwan's rapid economic development. Therefore, the rural-to-urban migration would have attenuated our estimates.

Like other studies that investigate long-term effects, we also face an identification threat of mortality selection. This is because our data consist only of individuals who lived to the age of at least 50. Since survivors tend to be more physically robust, it is possible that we underestimate the effects of DDT. Nevertheless, our estimation results do still show significant negative effects on education and employment, which suggests the existence of long-term consequences. The real effects may exceed our estimates.

To estimate the impact of DDT on education, we adopted the following empirical specification:

$$S_{ibc} = \alpha_0 + \alpha_1 DDT_{bc} + \gamma_b + \theta_c + \varepsilon_{ibc},\ b = 1953, 1954, \ldots, 1959, \quad (1)$$

where S_{ibc} denotes the years of schooling for individual i born in year b in township c; DDT denotes DDT exposure as measured by the total number of DDT sprayings for birth cohort b in township c; γ and θ represent cohort and township fixed effects, respectively; and ε is random error. We ran both linear and non-linear specifications for DDT exposure. The linear specification used the total number of DDT sprayings, while the non-linear specification consisted of a full set of dummy variables indicating different numbers of sprayings. We use robust standard errors clustered at the township level for statistical inferences.

A caveat is that Taiwan extended its compulsory education requirement from 6 to 9 years in 1968. This policy change affected the cohorts born in and after 1956. Since the law was adopted universally throughout Taiwan, this policy effect should be captured by the cohort fixed effect in equation (1).

To estimate the impact of DDT on employment, we adopted the following empirical specification:

$$E_{itbc} = \beta_0 + \beta_1 DDT_{bc} + \tau_b + \sigma_c + \epsilon_{itbc},\ b = 1953, 1954, \ldots, 1959, t = 1, 2, \ldots, 60, \qquad (2)$$

where E_{itbc} is an employment status dummy variable for individual *i* born in year *b* in township *c* in month *t* at age 49–53 (i.e., *t* = 1 is the observation for an individual in the first month after turning 49). The dummy variable equals one if the individual had a job that paid above the minimum wage, and zero otherwise. All other notations are defined as in equation (1). To mitigate the possible deflation of standard errors due to the presence of multiple observations for each individual, we used robust standard errors clustered at the individual level for statistical inferences when it comes to the regressions of employment.

For economic outcomes, we looked only at education attainment and employment status. Ideally, we should have also examined DDT exposure's impact on income. However, we do not have very good data on income. The National Health Insurance Research Database does keep records of each individual's income for the purpose of calculating insurance premiums (which are proportional to income). While in most cases an individual's income is reported to the National Health Insurance Administration by his/her employer, some individuals' income was self-reported (especially the income of the self-employed or employees in the informal sector), and they tend to under-report to lower their insurance premiums and income tax.

We ran all regressions for men and women separately. The coefficient α_1 and β_1 are the key estimates of the DDT exposure effect. The key underlying assumption is that after controlling for the birth cohort and township fixed effects, the variation in DDT exposure in early childhood is independent from any unobserved heterogeneity that affects individuals' outcomes in adulthood. However, given the potential bias resulting from within-county migration and mortality selection, we suspect that our estimates are likely smaller than the true effects.

4. Data

We collected DDT spraying data from various *Taiwan Province Gazettes* published by the Taiwan provincial government. The gazettes record the townships sprayed, as well as the related budget and staff information, for every year over the period when DDT was used in Taiwan. This allowed us to calculate the total number of DDT sprayings in each township over this period and, more importantly, the total number of DDT sprayings that each birth cohort in each township was exposed to at age 0–5.

Instead of samples, our empirical analysis uses population-wide data from two sources: the 2000 *Population and Housing Census* (hereafter the 2000 Census) and the Health Insurance Registry for Beneficiaries Files (code-named Health-08) from the National Health Insurance Research Database. The 2000 Census was administered and maintained by the Directorate General of Budget, Accounting and Statistics (DGBAS). The 2000 Census data contain information on individuals' education attainment, as well as sex, date of birth, birth county (recorded in the first digit of National ID number), and residence at the time of the census.

The National Health Insurance (NHI) is universal and compulsory. It therefore covers the entire population. The National Health Insurance Research Database (NHIRD) is maintained by the Ministry of Health and Welfare. The NHIRD contains each enrollee's basic demographic information, such as sex, date of birth, and current residence. It also includes monthly labor income as reported to the NHI Administration every month for the purpose of calculating the premium to be levied from the enrollee and his/her employer. The employees' monthly income is reported by the employer. If someone is self-employed or employed in the informal sector, he/she can sign up for the NHI through trade associations, unions, farmers' associations, or fishermen's associations. He/she then has to self-report his or her monthly income to the respective union or association, which passes it on to the NHI Administration. Unemployed residents sign up the NHI through their local council or as dependents of someone who has a job, and their labor income is recorded as zero.

While the NHIRD has a wealth of labor income data for the entire population, it must be used with caution for the following reasons. First, self-reported income is likely to be underreported to lower the premiums. However, the unions and associations do not allow members to report labor income below the national minimum wage. In other words, the lowest income that one can self-report is the minimum wage. Second, the NHIRD does not include any other income sources besides the one reported. Third, the NHIRD does not record any employment information other than the reported labor income. Therefore, there is no way to know if someone has multiple jobs or what hours an employee works.

Given these limitations, we decided to make the best of the available information by constructing a dummy variable, which is equal to one if a person has a reported monthly labor income above minimum wage, and to zero otherwise. We called this variable the Above-Minimum-Wage (AMW) job. This way, we made sure that even with the possibility of underreported income, people with a value of one had higher income than people with a value of zero. We did not expect that anyone would over-report their income. We used every individual's employment data for age 49–53, when most people are still active in the labor market. This amounts to a total of 60 observations per person. We excluded individuals who worked in the fishery or agricultural sectors, because their employment data are less accurate due to the nature of the sectors.[6]

[6] Some farmers and fishermen may work in other sectors in the down seasons. Moreover, enrollees of Farmers' Insurance and Fishermen's Insurance receive other benefits (e.g., pension), which means that there are incentives for people to sign up for these insurance policies even if their jobs are in other sectors.

Finally, we restricted the data to only those individuals who still lived in their birth county in 2000 in order to mitigate the migration bias. We did so by using each individual's national ID number, which begins with an alphabet followed by nine numerals. The alphabet is generally determined by the birth county.

Table 1 summarizes the data of our main analysis sample, which consists of 660,988 men and 523,644 women born between 1953 and 1959 who still lived in their birth county according to the 2000 Census. Although it comes from a different data source, the AMW job variable has almost the same number of men and women (indicated in parentheses in column (1)). The observations for the AMW job are about 60 times the number of men and women, with about 3% and 2% of values missing for men and women, respectively.

In our data, men had on average 10 years of schooling, while women had 9 years. In terms of employment, about 40% of men had a job that paid above minimum wage, while only 31% of women had such a job. Again, this is based only on the income reported to the NHI Administration. As for their DDT exposure, both men and women experienced on average 1.2 sprayings in their early childhood. More specifically, about 19% experienced only one spraying; 11%, two sprayings; 16%, three sprayings; 5%, four sprayings; and less than 2%, five or six sprayings. The remaining 47% had never been exposed to DDT.

5. Results

5.1 *Main Results*

The estimation results for years of schooling are reported in Table 2. Panel A reports the linear effect, and Panel B, the non-linear effect. As shown in Panel A, the linear effect specification for both men and women suggests that every additional DDT spraying is on average associated with a reduction in schooling by about 0.04 years. If a person was exposed to 6 sprays, he/she would have 0.24 years of schooling less than her counterpart with no exposure at all. However, Panel B suggests that the effect does not seem to be linear. The largest effect appears to occur at the first spraying, which caused a reduction in schooling of about 0.13 years. The incremental changes after the first spraying are much smaller and could even go in the opposite direction to some extent. The dose-response curve of the effect of DDT on schooling is non-linear.

Table 3 reports the effect on the probability of having an AMW job. Panel A shows that one DDT spraying is associated with a decrease in the probability of having an AMW job by about 0.25 percentage points. This is the same for both men and women. Nevertheless, Panel B again shows a clear non-linear dose-response curve for the DDT effect. Overall, the results from Tables 2 and 3 suggest that DDT exposure in early childhood is associated with less schooling and worse employment outcomes in adulthood.

5.2 *Using the Extended Cohort*

We chose to use the cohort born in and after 1953 in order to avoid the correlation between DDT and malaria. Our concern was that the correlation would lead to an overestimation of the DDT effect. To verify this conjecture, we additionally included individuals born in 1951 and 1952, who were exposed to both rampant malaria and multiple DDT sprayings in early childhood. This implies that the 1951–1952 cohorts were exposed to the harmful effects of both malaria and DDT. As shown in Table 4, we did find that the estimates were indeed larger due to the "double jeopardy."

5.3 *Inclusion of Migrants*

As previously discussed, migration could attenuate our estimates, because individuals who were exposed may have been included in the control group, and some individuals who should have been in the control group may have been instead included in the treatment group. In Table 5, we still used the 1953–1959 cohort, but also added the migrants who no longer lived in their birth county when the data were collected. As expected, the estimated effects are much smaller. Compared to the main results, the effect on schooling dropped by about

65%, and the effect on AMW job, by 45%. Note that in the main results, we still cannot rule out within-county migration, implying that the main results are likely also underestimated.

6. Conclusion

DDT is still being used as a cheap and effective vector control method for malaria in many endemic developing countries. However, this paper shows that exposure to DDT in early childhood can have long-term negative impacts on socioeconomic outcomes in adulthood. We exploited the variation in DDT exposure in early childhood resulting from the large-scale malaria eradication campaign carried out in Taiwan in the 1950s, which consisted of multiple indoor residual sprayings of DDT over several years, even though malaria had been quickly brought under control very early in the campaign. We found that DDT exposure in early childhood is associated with lower education and worse employment in adulthood. Although our estimated effects are small, they are likely attenuated because of migration and mortality selection. Our paper, together with previous research on the health effects of DDT, suggests that this anti-malaria measure is not as “cheap” as we once thought if the long-term costs are included.

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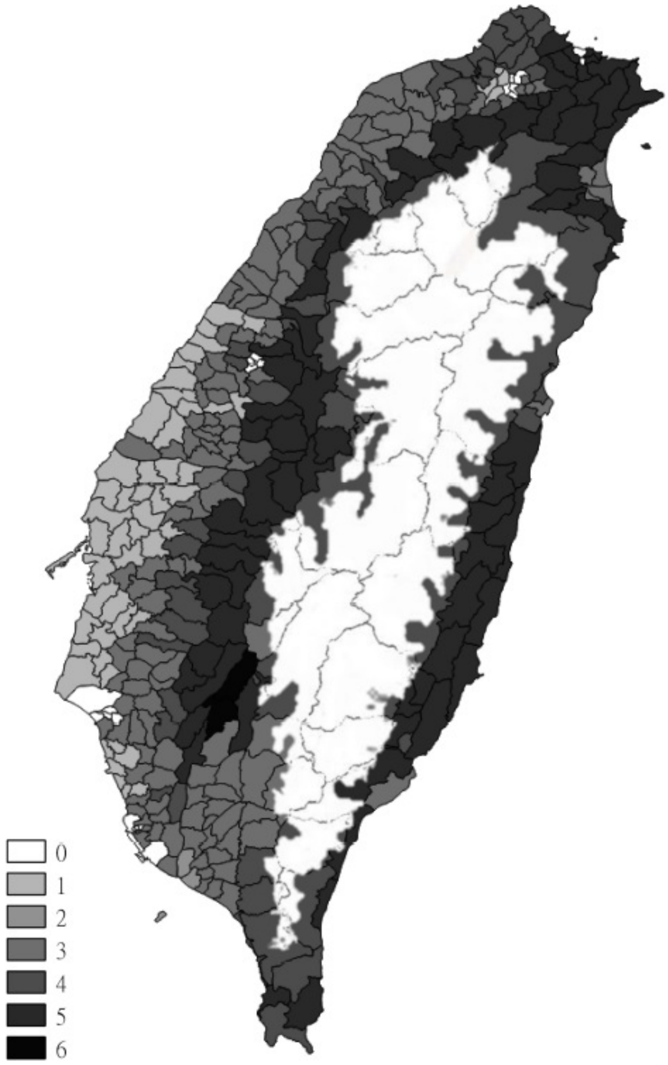
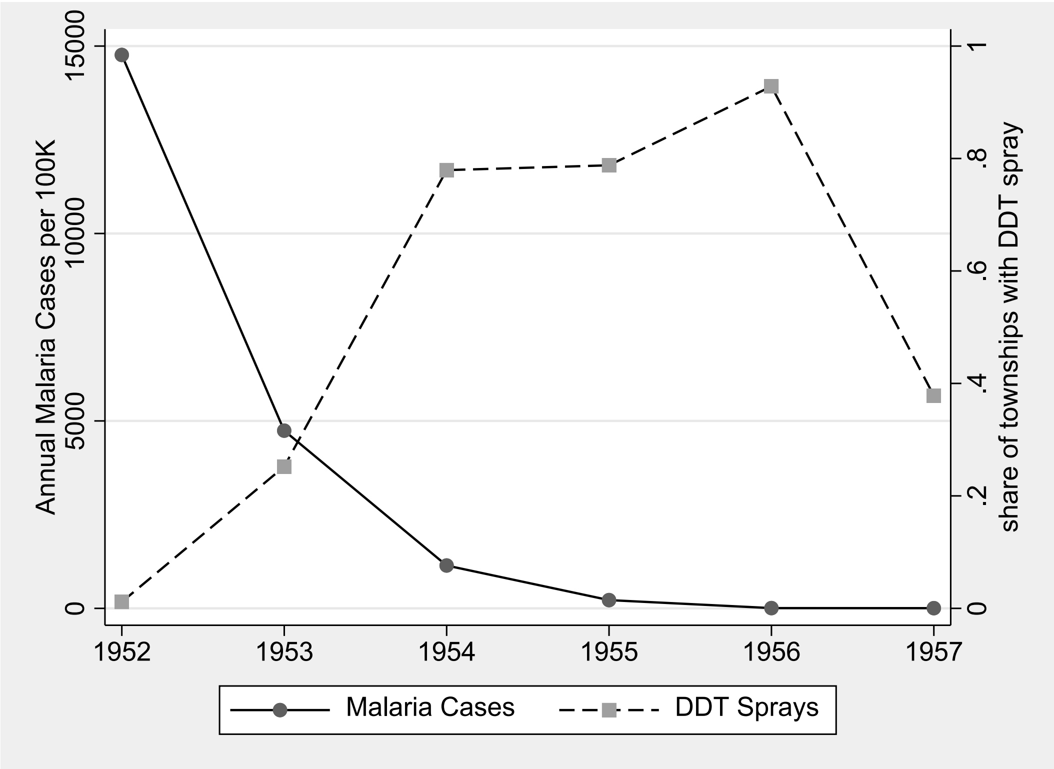
Figure 1. DDT Sprayings 1952–1957



Notes: The numbers indicate the total number DDT sprayings between 1952 and 1957.
Source: The authors' own calculations based on data collected from various *Taiwan Province Gazettes* published between 1952 and 1957.

Figure 2. Malaria Prevalence Rate and the Share of Townships That Received DDT Sprayings



Notes: The malaria prevalence rate is the number of annual malaria cases divided by the population times 100,000.
Sources: The data on malaria cases are obtained from *Malaria Eradication in Taiwan* by the Department of Health, Executive Yuan, R. O. C.; population data are obtained from the Department of Household Registration, M. O. I., Taiwan; information about DDT sprayings in 1953–1957 is collected from various *Taiwan Province Gazettes* published between 1952 and 1957.

Table 1. Summary Statistics[a]					
	Obs	Mean	SD	Min	Max
	(1)	(2)	(3)	(4)	(5)
	Panel A: Men				
Years of schooling	660,988	10.376	3.339	0	23
AMW job (%)[b]	38,342,783	0.402	0.490	0	1
(number of individuals)	(661,006)				
Childhood DDT exposure:					
1 spraying (%)	660,988	0.191	0.393	0	1
2 sprayings (%)	660,988	0.109	0.312	0	1
3 sprayings (%)	660,988	0.160	0.367	0	1
4 sprayings (%)	660,988	0.051	0.221	0	1
5 or 6 sprayings (%)	660,988	0.018	0.134	0	1
Number of total sprayings	660,988	1.186	1.393	0	6
	Panel B: Women				
Years of schooling	523,644	9.223	3.600	0	23
AMW job (%)[b]	30,884,748	0.305	0.461	0	1
(number of individuals)	(523,658)				
Childhood DDT exposure:					
1 spraying (%)	523,644	0.190	0.392	0	1
2 sprayings (%)	523,644	0.110	0.313	0	1
3 sprayings (%)	523,644	0.166	0.372	0	1
4 sprayings (%)	523,644	0.050	0.217	0	1
5 or 6 sprayings (%)	523,644	0.018	0.133	0	1
Number of total sprayings	523,644	1.198	1.392	0	6

Notes: *a*. The data consist of individuals born in 1953–1959. *b*. Above-minimum-wage (AMW) job is a dummy variable equal to one if a person has a job that pays above minimum wage and zero if a person is paid minimum wage or less or has no income. AMW job is a monthly variable, and each individual has about 60 observations for age 49–53. However, about 3% of observations are missing for men, and about 2%, for women.

Sources: Years of schooling come from the *2000 Population and Housing Census*. AMW job data are from the *National Health Insurance Research Database*. DDT spraying information comes from various *Taiwan Province Gazettes*.

Table 2: Estimates of DDT Effect on Years of Schooling		
	Men	Women
	(1)	(2)
	Panel A: Linear effect	
DDT sprayings	−0.0403**	−0.0383**
	(0.0157)	(0.0184)
	Panel B: Nonlinear effect	
1 spraying	−0.1282***	−0.1305***
	(0.0302)	(0.0370)
2 sprayings	−0.0904**	−0.1539***
	(0.0424)	(0.0490)
3 sprayings	−0.1445***	−0.1728***
	(0.0514)	(0.0602)
4 sprayings	−0.2391***	−0.1897***
	(0.0680)	(0.0868)
5 or 6 sprayings	−0.2517***	−0.2204**
	(0.0847)	(0.1007)
Obs	660,988	523,644
Number of townships	349	349

Notes: The dependent variable is the years of schooling. Panel A uses the total number of DDT sprayings as the regressor. Panel B uses dummy variables to indicate each level of DDT sprayings, with zero sprayings as the reference group. All regressions additionally control for a full set of birth cohort dummies and township dummies. Robust standard errors clustered at the level of the current township of residence are in parentheses. ***, ** and * indicate significance at 1%, 5%, and 10%.

Sources: The years of schooling come from the *2000 Population and Housing Census*. DDT spraying information comes from various *Taiwan Province Gazettes*.

Table 3: Estimates of DDT Effect on the Probability of Having an Above-Minimum-Wage Job

	Men	Women
	(1)	(2)
	Panel A: Linear effect	
DDT sprayings	−0.0025***	−0.0025**
	(0.0009)	(0.0010)
	Panel B: Nonlinear effect	
1 spraying	−0.0058**	−0.0088***
	(0.0027)	(0.0028)
2 sprayings	−0.0092***	−0.0140***
	(0.0034)	(0.0036)
3 sprayings	−0.0107***	−0.0112***
	(0.0035)	(0.0037)
4 sprayings	−0.0096**	−0.0091*
	(0.0046)	(0.0048)
5 or 6 sprayings	−0.0130**	−0.0163***
	(0.0058)	(0.0060)
Obs	38,342,783	308,84,748
Number of individuals	661,006	523,658
Number of townships	349	349

Notes: The dependent variable is a dummy variable equal to one if a person has an above-minimum-wage job and zero otherwise. This is a monthly variable, and each individual has about 60 monthly observations for age 49–53. Panel A uses the total number of DDT sprayings as the regressor. Panel B uses dummy variables to indicate each level of DDT spraying, with zero sprayings as the reference group. All regressions additionally control for a full set of birth cohort dummies and township dummies. Robust standard errors clustered at the individual level are in parentheses. ***, ** and * indicate significance at 1%, 5%, and 10%.

Sources: AMW job information is from the *National Health Insurance Research Database*. DDT spraying information comes from various *Taiwan Province Gazettes*.

Table 4: Estimates of DDT Effects Using the Extended Cohort of 1951–1959

	Men	Women
	(1)	(2)
	Panel A: Years of schooling	
DDT sprayings	−0.0490***	−0.0497***
	(0.0173)	(0.0185)
Mean of dep. var.	10.165	8.952
Obs	830,882	661,922
Number of townships	349	349
	Panel B: Having an AMW job (%)	
DDT sprayings	−0.0025***	−0.0027***
	(0.0008)	(0.0008)
Mean of dep. var.	0.398	0.300
Obs	48,296,134	39,070,522
Number of individuals	830,900	661,936
Number of townships	349	349

Notes: The data consist of individuals born in 1951–1959. The dependent variable is the years of schooling in Panel A, and a dummy variable indicating whether a person has an above-minimum-wage job in Panel B. All regressions additionally control for a full set of birth cohort dummies and township dummies. Robust standard errors clustered at the level of the current township of residence in Panel A and at individuals in Panel B are in parentheses. ***, ** and * indicate significance at 1%, 5%, and 10%.

Sources: Years of schooling information comes from the *2000 Population and Housing Census*. AMW job information is from the *National Health Insurance Research Database*. DDT spraying information comes from various *Taiwan Province Gazettes*.

Table 5: Estimates of DDT Effects: 1953–1959 Cohort Including Migrants		
	Men	Women
	(1)	(2)
	Panel A: Years of schooling	
DDT sprayings	−0.0142	−0.0144
	(0.0183)	(0.0147)
Mean of dep. var.	10.776	9.485
Obs	1,128,628	1,140,140
Number of townships	349	349
	Panel B: Having an AMW job (%)	
DDT sprayings	−0.0014**	−0.0012*
	(0.0007)	(0.0007)
Mean of dep. var.	0.398	0.300
Obs	65,507,525	67,197,838
Number of individuals	1,128,660	1,140,169
Number of townships	349	349

Notes: The data consists of individuals born in 1953–1959, including migrants who did not live in their birth county in 2000. The dependent variable is the years of schooling in Panel A, and a dummy variable indicating whether a person has an above-minimum-wage job in Panel B. All regressions additionally control for a full set of birth cohort dummies and township dummies. Robust standard errors clustered at the level of the current township of residence in Panel A and at the level of individuals in Panel B are in parentheses. ***, ** and * indicate significance at 1%, 5%, and 10%.

Sources: Years of schooling data come from the *2000 Population and Housing Census*. AMW job information is from the *National Health Insurance Research Database*. DDT spraying information comes from various *Taiwan Province Gazettes*.

Appendix

Table A1. Five-Year Migration Patterns

	Panel A: Whole population	
	1975–1980	1985–1990
	(1)	(2)
(1) Same village	70.18%	74.31%
(2) Same township, different village	9.89%	7.4%
(3) Same county, different township	8.26%	7.48%
(4) Within Taiwan, different county	11.38%	10.44%
(5) Outside Taiwan	0.29%	0.39%
(6) Staying in same township (1+2)	80.07%	81.71%
	Panel B: Only cohort 1951–1959	
	1975–1980	1985–1990
	(1)	(2)
(1) Same village	61.66%	69.91%
(2) Same township, different village	9.94%	9.33%
(3) Same county, different township	10.02%	9.78%
(4) Within Taiwan, different county	18%	10.42%
(5) Outside Taiwan	0.38%	0.55%
(6) Staying in same township (1+2)	71.6%	79.24%

Notes: Respondents aged five and older reported their residence five years ago in the five categories listed (1– 5).
Sources: 1980 & 1990 *Population and Housing Censuses*